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(54) Equaliser for radio receiver.

(57) A GMSK radio receiver for operation in presence of strong multipath interference, comprising a baseband frequency converter which operates to produce I and Q baseband GMSK signals, which will be distorted by any multipath interference present are correlated with a plurality of different possible signals to afford in respect of each correlation a probability signals, the probability signals being processed to determine the significance of the signal received, whereby transmitted data is determined in the presence of multipath interference.

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IMPROVEMENTS IN O ATING TO EQUALISERS

This invention relates to equalisers for radi vers of the kind destined for operation in the presence of strong multipath interference.

Mobile telephones, for example, include sceiver of which the receiver receives transmission signals from a base station via a multitude of paths. The transmission signals are usually frequency modulated signals and the carrier frequency is The multipath interference can produce signal paths of length equal to a delay equivalent to up to fo of original data used to modulate the carrier wave. In particular, digital data or voice communications sphere are frequently of the Gaussian Minimum Shift Keying (GMSK) type. The receiver includes eband frequency converter which demodulates the received transmissions to provide I and Q ba GMSK signals distorted by the multipath inteference present.

The data to be transmitted is arranged kets and each packet is transmitted with a header including an address and a predetermined dat ence. This predetermined data sequence is employed in estimating the "channel impulse response" (nal distortion due to the multi-path interference).

If the channel impulse is determined, sub t transmitted data bits, depending on the preceeding bits can be interpreted on a probability basis.

It is possible using a Viterbi algorithm to e the received GMSK signals with all possible signals and to select, on the basis of probability, the m ly signal. This most likely signal is assumed to be the original signal.

An apparatus to effect a complete comp employing the Viterbi algorithm, would be complex, expensive, and of size and power requiremen that it would not constitute a commerical solution of the problem of multipath interference; particula ceivers such as those used in mobile telephones.

It is an object of the present invention to p an equaliser for a radio receiver wherein the aforesaid disadvantages are overcome.

According to the present invention, there ided an equaliser, for a radio receiver, comprising a converter for producing, from a received sig gital samples at baseband, means for producing an estimate of channel distortion in the receivec l, a store in which are stored signal sets, means for applying the distortion estimate to the stored s ets, metric generating means for generating metrics of selected modulated signal sets with the digi ples and a processor for processing the generated metrics in accordance with a Viterbi algorithm mine the most probable value of the received signal.

The invention will be described further, y of example, with reference to the accompanying drawings, in which:-

Figure 1 is a block schematic diagram of a receiver including an equaliser according to the present invention;

Figure 2 is a block schematic diagram o ric generator forming part of the equaliser of Figure 1;

Figure 3 is a block schematic diagram o ric calculator of the metric generator of Figure 2;

Figure 4 is a block schematic diagram o al selector of the metric generator of Figure 2; and

Figure 5 is an 8-state trellis diagram.

In the example hereinafter described, it is ed that voice or data signals are transmitted in packets by a known system using Gaussian Minimum eying (GMSK). In such a system, the information to be transmitted is converted to digital form and is d through a Gaussian filter. The individual bits of the digitized information are thereby modified i ndance upon one or more preceding bits. The so modified signals may then be encoded (or m been encoded before passage through the Gaussian filter) and used to frequency modulate a carrie The modulated carrier wave having, as its modulation, the digitized, modified encoded information, is itted.

As stated above, the information is trar d in packets and each packet comprises a header including a predetermined bit sequence and ar ss.

A base station transmits the modulated , to mobile receivers (transceivers) such as mobile telephones. Where the transmission is effe a city environment, reflections from buildings, for example, causes multipath interference so tha ceived signal may include echoes (caused by different path lengths of reflected signals) along with th ed signal. The different path lengths may distort each wanted signal by the preceeding signals ov eriod 4T equivalent to the transmission time of for example, four data bits of the wanted signal (w is the bit interval).

The invention is directed to extracting nted signal from the distorted signal caused by the multipath inteference.

Referring now to Figure 1, a distorted

converter 10.

The converter 10 outputs I and Q basel

In each packet, the first part of the

sequence. The baseband GMSK signals

analogue to digital values in an A to D c

predetermined bit sequence, is fed to a ch

The distortion of this known predeterm

estimated. The channel impulse response

affected the transmitted information. The

signals, from a store 18, in a convolutor 16

selector 20, are fed to a metric generator

also fed. The metrics so generated are

algorithms (as indicated in the trellis dia

detected data, at its output and, in depend

bit" back to the selector 20.

A path store is provided in which prec

bits, selection of corresponding signal sets

appropriate metrics in the next data bit inte

The store 18 only holds a reduced set

By using an averaging technique, in a

sequences can be reduced to 32. The av

described below.

At the receiver, a set of signals would

the transmitted signal in the interval -4T <

storing 128 patterns, corresponding to a

produce one of the waveforms. Denoting

dependence of the modulated waveform o

0 →
-T -
-2T
-3T
-4T

Due to the nature of the filtering appl

the value of the transmitted waveform tha

averaging technique is used to produce a

To form the approximate waveform, fc

a) n = 0

$$s(t_1\underline{a}) \approx g_o(t)$$

where $g_o(t) = < \exp (j2\pi h\, a_o\, q(t)) > a_o$

(<> a_o denotes an averaging over a_o.)

ϕ' is the redefined phase state

d signal is passed from the aerial to baseband frequency

storted GMSK signals.

d received signal corresponds to the predetermined bit

oise are sampled at bit frequency and converted from

ır 12. The initial part of the GMSK signal sequence, the

npulse response estimator 14.

it sequence enables a "channel impulse response" to be

neasure of the distortion, caused by echoes, which has

estimate may be applied to each of a series of stored

ıe most appropriate stored signal sequences, selected in a

vhich, on a bit-by-bit basis, the baseband GMSK signal is

) the Viterbi processor 24 which applies known Viterbi

f Figure 3) to produce the most probable sequence, as

ɔon the probable sequence selected, an output of the "last

ıits are stored. Depending on the value of these preceding

de for feeding to the metric generator 22 for generation of

sible data sequences. A full set requires 128 combinations.

nce with the present invention, this number of stored

ı technique to reduce the number of stored sequences is

lly be stored corresponding to all possible combinations of

T = bit duration). For the full state equaliser this involves

ɔinations of a 7-bit sequence that, when modulated, will

it response as a_0 ..... a_{-6} (each a_i taking ± 1), then the

dual bits in a given time interval is thus:-

bits
a_0, a_{-1}, a_{-2}
a_{-1}, a_{-2}, a_{-3}
a_{-2}, a_{-3}, a_{-4}
a_{-3}, a_{-4}, a_{-5}
a_{-4}, a_{-5}, a_{-6}.

ɔr to modulation, the bits a_0 and a_{-6} have less effect upon

$_{-5}$ ..... a_{-1}. Rather than completely ignoring their effect, an

signals that sufficiently approximate the true signal set.

and n = -4, s(t,a) is modified in such a manner:-

$$(j2\pi h \sum_{i=-5}^{-1} a_i\, q(t-iT)) \exp (j\emptyset')$$

$$(\emptyset' \quad \iota \sum_{i=-\infty}^{-6} a_i)$$

b) n = -4

$$s(t_1\underline{a}) \approx g_{-4}(t) \exp \quad h \sum_{i=-5}^{-4} a_i\, q(t-iT)) \exp\,(j\emptyset')$$

$g_{-6}(t) = < \exp(j\pi h\, a_{-6}\,\{q(t+6T) - \tfrac{1}{2}\})' > a_{-6}$

The function q(t) has the form:-

$$q(t) = \begin{cases} 0 & t \le 0 \\ \int_{-\infty}^{t} g(u)\,du & \\ 1/2 & t > LT \end{cases}$$

where g(u) is the response of a Gaussian low p er to a data symbol.

It will be seen from the above mathema xplanation that all seven bit data sequences can be closely approximated by only 5 bit data seque

Similarly, the selection of signal sets in lector 20 for feeding to the metric generator can be described mathematically with reference to Fig and 4 of the accompanying drawings.

In constructing the selected signal set for the metric generator 22, for a full state equaliser which would handle delays of up to 4T, all possit nbinations of sequences of length 7 symbols would normally be required at the receiver. To redu complexity at this stage, the averaging technique as described above is performed, so that only se es of length 5 symbols are required in constructing the signal set. If the modulated data sequence is ed by $s(t,\underline{a})$, where $\underline{a}$ is the aforementioned 5 bit data sequence, then the signal set $(c(t,\underline{a}))$ is formec gh the complex convolution in the convolutor 16, of the estimated channel impulse response (h(t)) witl nodulated data sequence. Also required is the squared modulus of the signal set $(|c(t,\underline{a})|^2)$. The metric eeds to be generated by the generator 22 is given by

$$\Gamma(\underline{a}) = \mathrm{Re}\{\int_{nT}^{(n+1)T} r(t)c^*(t,\underline{a})\,d \quad 5\int_{nT}^{(n+1)T} |c(t,\underline{a})|^2 dt \qquad (1.1)$$

Where r(t) = I(t) + jQ(t), is the received s

The only implication of the averaging to r the length of the sequence $\underline{a}$ is that detection starts on the previous symbol transmitted rather than th ent symbol; i.e. for a path memory length of N symbols the Viterbi algorithm would give an estimate o mbol a_{n-N} rather than the symbol a_{n-N+1} of the full state case (a_n denotes the current symbol).

In calculating the signal set, it should be hat only half of the modulated data sequences need to be stored. Further in convolving the modulate with the channel impulse response estimate, only these sequences need be used. To generate the rer half of the signal set it is only necessary to sum terms involving the imaginary part of the sequence s ith differing sign. This is described mathematically as:

Denote sequence with opposite sign as -a he signals for these sequences are generated as:

$\mathrm{Re}\{c(t,\underline{a})\} = \mathrm{Re}\{s(t,\underline{a})\} \otimes \mathrm{Re}\{h(t)\} - |\mathrm{m}\{s(t,\underline{a})\} \otimes |$ } (1.2)

$|m\{c(t,\underline{a})\} = |m\{s(t,\underline{a})\} \otimes Re\{h(t)\} + Re\{s(t,\underline{a})$ $\eta(t)\}$ (1.3)

Further the multiplication by 0.5 in the ...us of the signal set (as in equation 1.1) need not be done if the store modulated data has the following

$s(t,\underline{a}) = (1/\sqrt{2}) \exp(j\phi(t,\underline{a}))$ (1.6)

...by $1/\sqrt{2}$.

The important point here is the multiplic... the signal selector 20 to the metric calculators 23 of the

The sixteen selected signal sets are fe... baseband GMSK signals. The generator 22 produces the metric generator 22 together with the sam... ted above.

metrics which are used in the processor 24

In calculating the metrics, it is only nec... to use one sample/symbol. Consequently the FIR filtering or correlation process reduces to a single ... cation. The effect of the accumulated phase in the metric generation process is to require the I and ... to be correlated with both the real and imaginary parts of the signal set, thus four correlators are us... generate one metric. However because the accumulated phase takes the values $0,\pi/2,\pi,3\pi/2$, it is or... essary to perform two of the correlations in correlators 25. Which pair depend upon the phase stat... anding expression 1.1 for the metric, and denoting the accumulated phase as 0 the process descri... ...ove is readily seen.

$$\Gamma(\underline{a}) = \cos(\theta) \left(\int_{nT}^{(n+1)T} Re\{c(t \quad t)\ dt + \int_{nT}^{(n+1)T} Im\{c(t,\underline{a})\}Q(t)\ dt\right)$$

$$+\sin(\theta) \left(\int_{nT}^{(n+1)T} Re\{c(t, \quad t)\ dt - \int_{nT}^{(n+1)T} Im\{c(t,\underline{a})\}I(t)\ dt\right)$$

$$- 0.5\int_{nT}^{(n+1)T} |c(t,\underline{a})|^2\ dt \qquad (3.1)$$

$$\theta = Mod_{2\pi}\left(\pi/2 \sum_{i=-\infty}^{m-4} a_i\right) \qquad (3.2)$$

As stated hereafter in the description ... processor 24, the selection of which signals to use in the generation of the metrics depends upon ... th store content, the phase states, (values of 0) are also determined from the path store. The metri... ration process for a given sequence $\underline{b}$ is shown in Figures 2 to 4.

The metrics generated in the generatc... :e fed to the processor 24 which determines probability on the basis of state trellis diagrams as showr... ure 5.

Given the sixteen signals, the number ... :es in the trellis is 64, which includes a set of phase states to account for the accumulated phase in ... nsmitted signal. This accumulated phase can take one of four values (when reduced modulo 2π): ... π, $3\pi/2$. The reduced state equaliser described does not incorporate the phase states. Instead, fo... state in the trellis, the accumulated phase is calculated based on the contents of the path store ... implication of this on the metric generation process was described above. To reduce further the nu... of states, a subset of the sequence $\underline{a}$ (sequence $\underline{b}$) is used in the Viterbi processing. The sequence $\underline{b}$... ength four symbols and consequently there are 8 states in the trellis diagram as shown in Figure 5.

With the phase states removed and th... aging technique as described above applied to reduce the length of the sequence $\underline{a}$. a 16 state e... r results. In this case the Viterbi algorithm performs the following task: a selection procedure is us... eep the number of sequences involved in the maximisation of the metric constant. This involves takin... ences that differ only in the symbol a_{m-4} (where $a_m = a_{n-1}$)

and selecting the sequence with the largest m
largest of the surviving metrics forms the bas
number of states to 8, the following modificatic
sequences that differ only in the symbol a_{m-4},
a_{m-3} are involved in the maximisation of the
there are two possible transitions. For each
generate the metric in the next symbol interval
depending upon the symbol a_{m-3}. To determin
symbol interval, the content of the path store i
the symbol a_{m-3}.

The values of the processed metrics are a
most probable signal. This is output for furth
voice and/or data communication.

Because averaging is used to reduce all p
the contents of the path store to control signal

This is performed over all such combinations, and the
the decision about the symbol a_{m-N+1}. To reduce the
ıe procedure outlined above is made: instead of taking
:quences of length 4 symbols, that differ in the symbol
In the 16 state equaliser, at each state in the trellis,
on, there is, at the receiver, a signal (c(t,a) used to
ıe 8 state case, there are now four possible transitions,
wo signals to use in generating the metric for the next
ined, hence a soft decision is made as to the nature of

d and the largest processed metric is equivalent to the
:essing to provide the data bit stream constituting the

7-bit values to 5-bit values, and because of the use of
on, a reduced state processor is possible.

Claims

1. An equaliser, for a radio receiver, co
digital samples at baseband, means for provic
store in which are stored signal sets, means
metric generating means for generating metri
and a processor for processing the generatec
the most probable value of the received signal

2. An equaliser as claimed in claim 1 whe
includes means for comparing a known dat
sequence and for deriving the estimate therefr

3. An equaliser as claimed in claim 1
representing averaged values of all possible 7

4. An equaliser as claimed in claim 3 incl
sixteen of stored signal sets which differ on
dependance upon the contents of the state pa

5. An equaliser as claimed in any preced
upon the symbol a_{m-3}, to reduce the equaliser

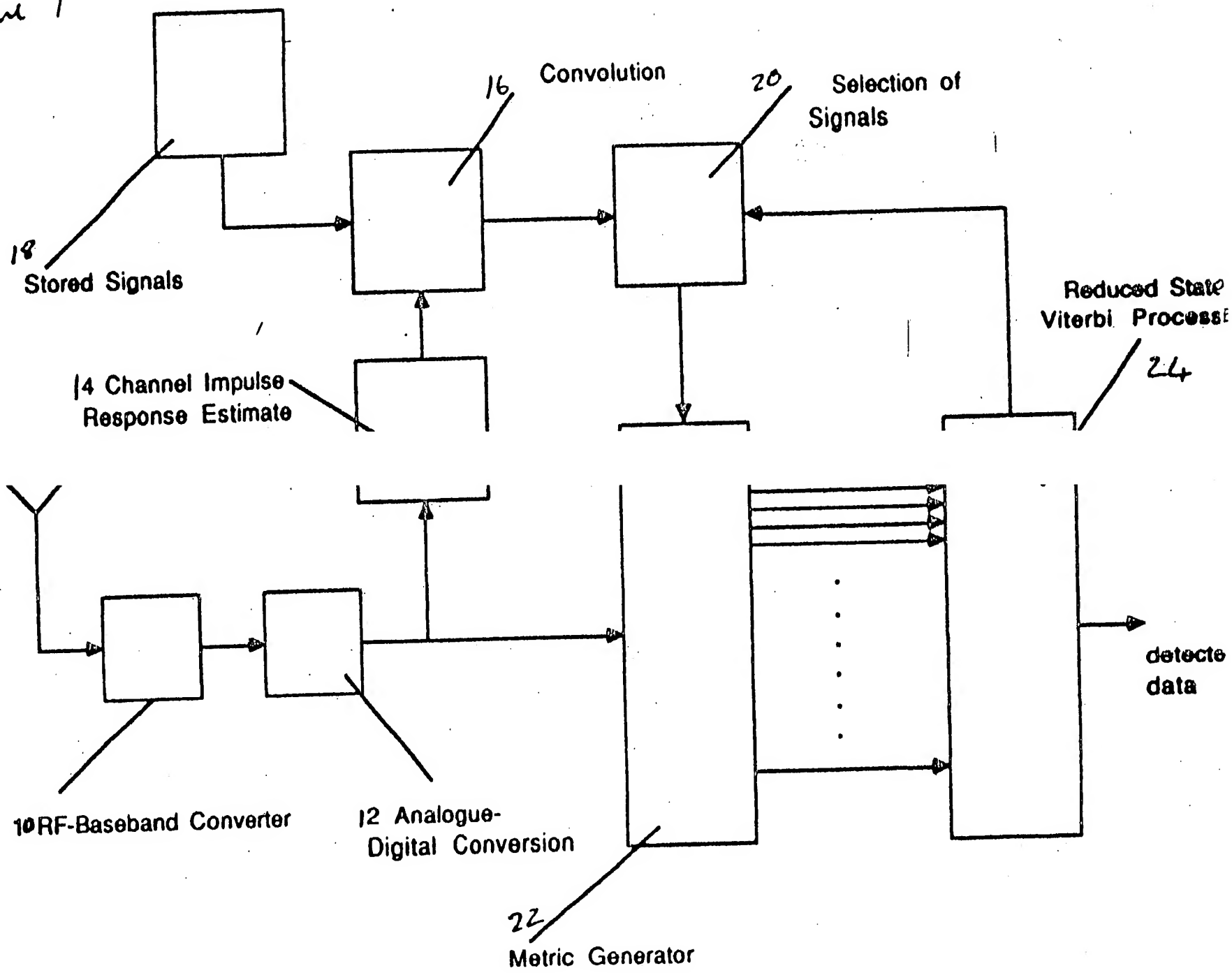
6. An equaliser, for a radio receiver, st
accompanying drawings.

ıg a converter for producing, from a received signal,
estimate of channel distortion in the received signal, a
ɔlying the distortion estimate to the stored signal sets,
elected modulated signal sets with the digital samples
:s in accordance with a Viterbi algorithm to determine

ɜ means for producing an estimate of channel distortion
ence, received as a distorted signal, with the known

wherein the stored signal sets are 5-bit sequences
ıuences.
ɜ state path store and means for selecting a sub-set of
ıe symbol a_{m-4}, for use in generating the metrics, in
ɜ.
m path store also provides a selection, in dependence
ɜ-state equaliser.
ally as hereinbefore described with reference to the

Figure 1


16
Convolution
20
Selection of Signals
18
Stored Signals
Reduced State Viterbi Processe
24
14 Channel Impulse Response Estimate
detecte data
10 RF-Baseband Converter
12 Analogue-Digital Conversion
22
Metric Generator

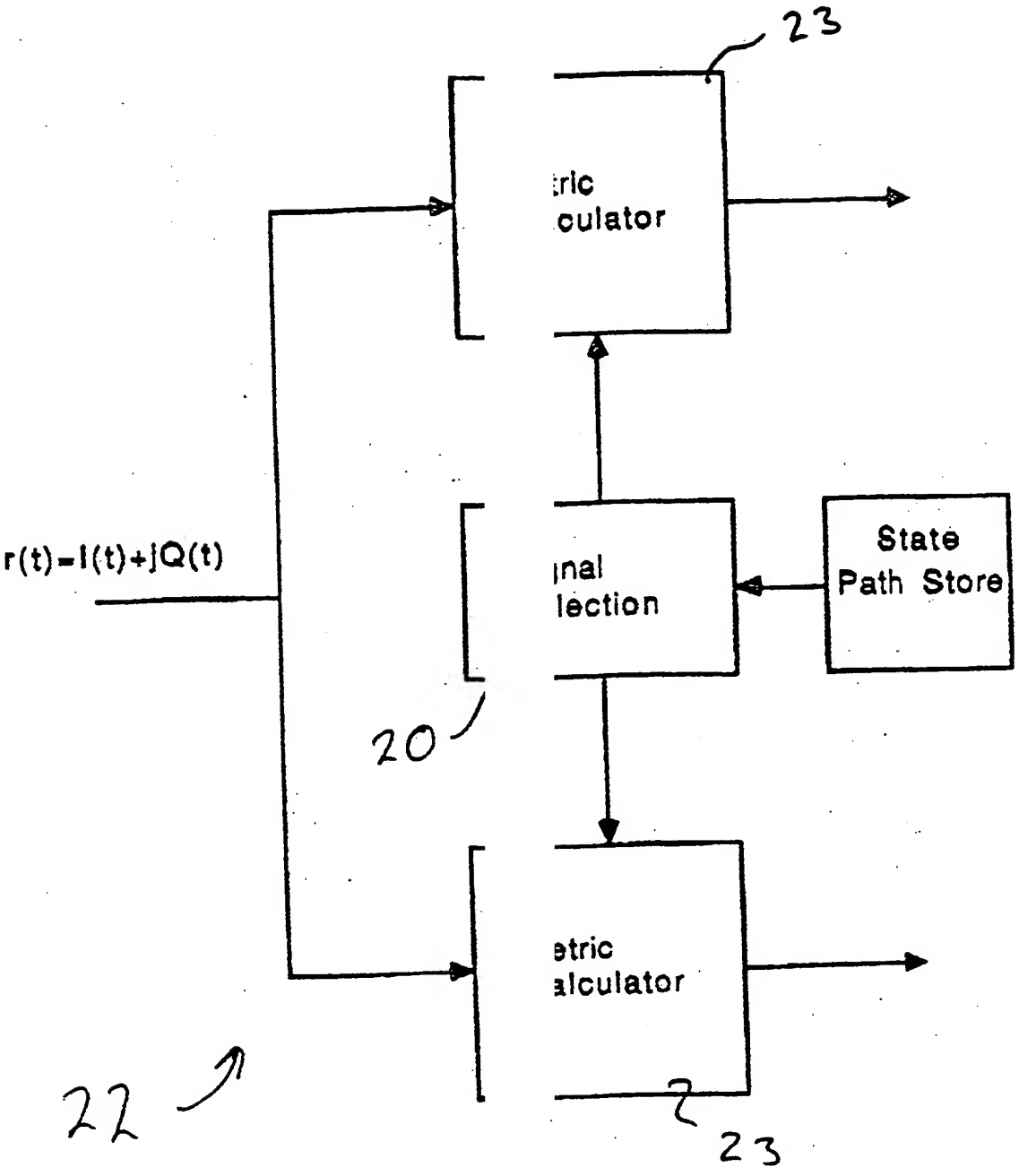


Fig.2

Metric Generation E nt for Reduced State Equaliser.

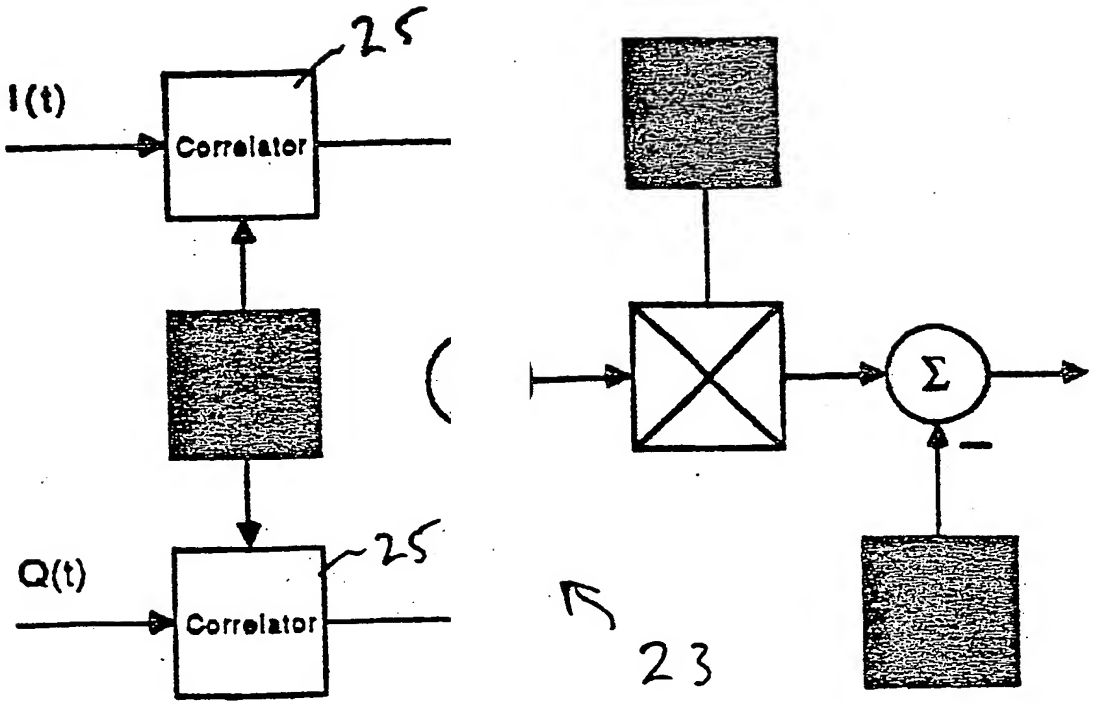


Fig. 3

Metric Calculat

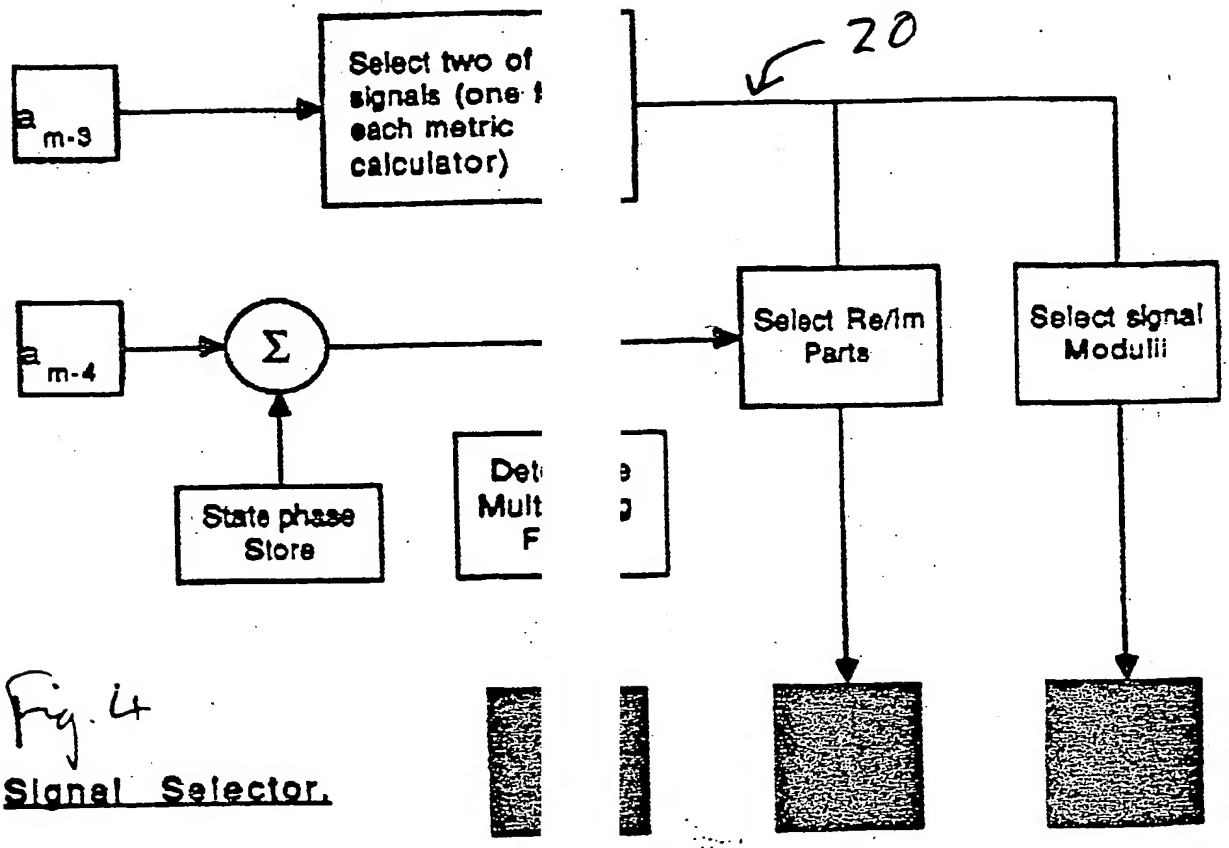
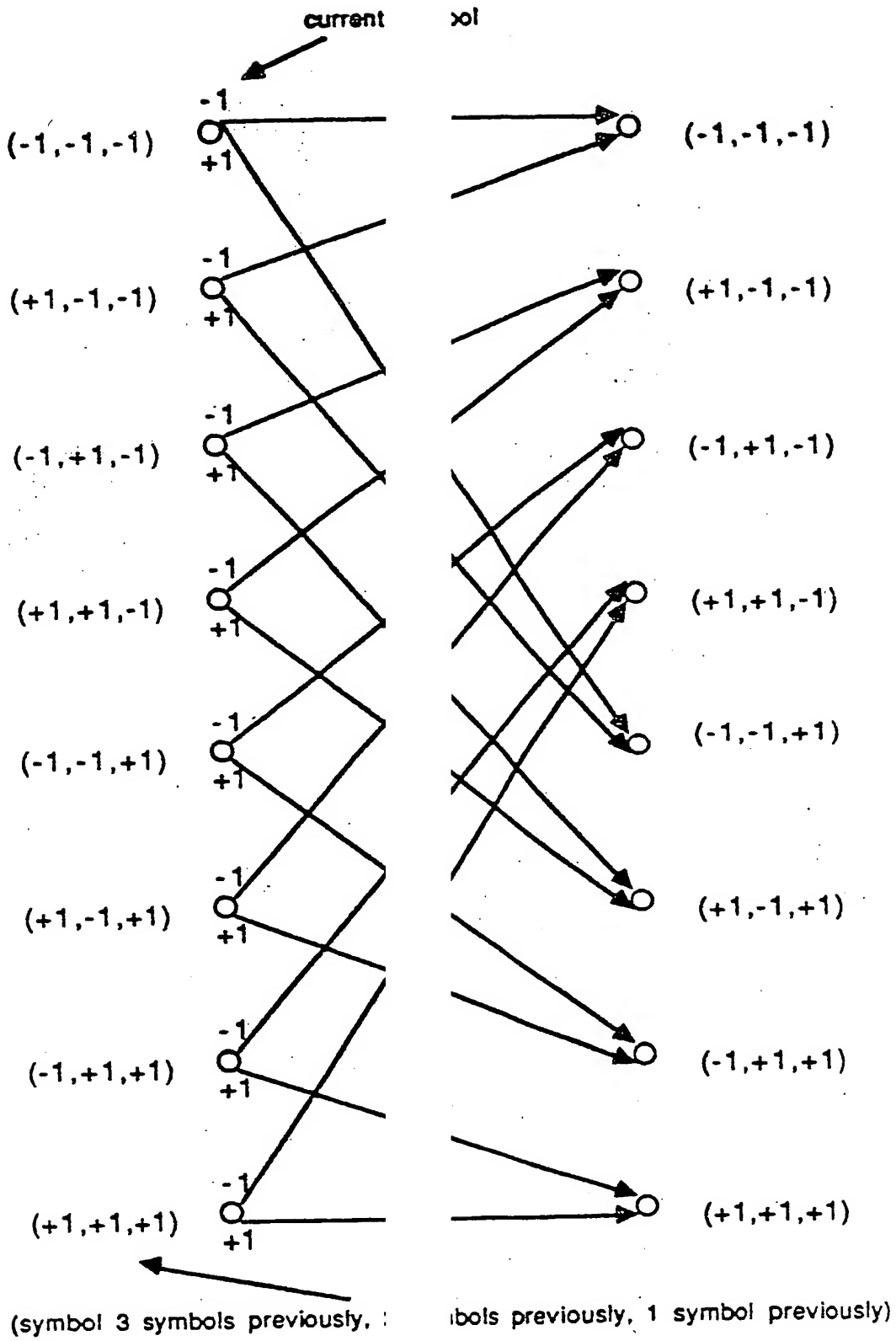


Fig. 4

Signal Selector.



Figur **8 State Trellis Diagram**

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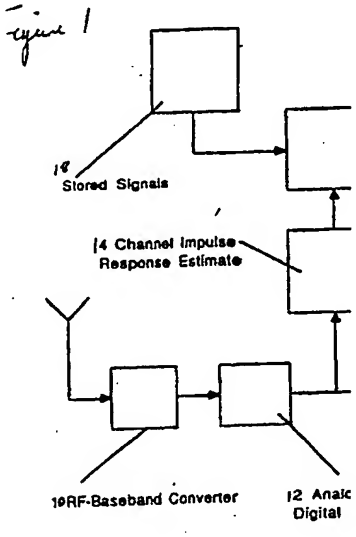

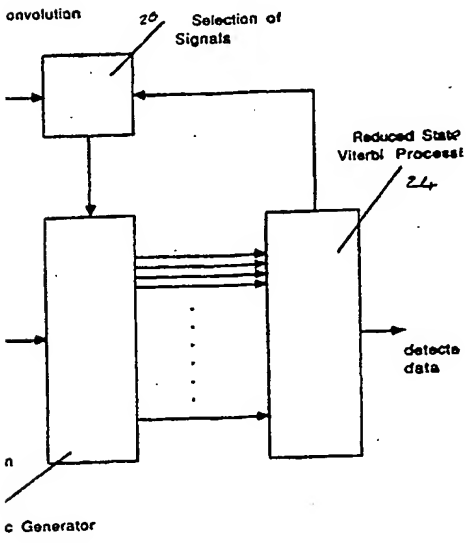

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DOCUMENTS CONSIDERED T E RELEVANT

Category	Citation of document with indication, whe of relevant passages	riate,	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	BELL SYSTEM TECHNICAL JOURNAL, vember 1973, pages 1541-1562; D.D. FA "Adaptive channel memory truncation for hood sequence estimation" * The whole document *	, no. 9, No- ER et al.: ıum likeli-	1-5	H 04 L 25/30
A	IEEE TRANSACTIONS ON INFORMATIC IT-19, no. 1, January 1973, pages 120-12 al.: "Adaptive maximum-likelihood seque digital signaling in the presence of intersy * The whole document *	ORY, vol. MAGEE et imation for nterference"	1-5	
A	DE-A-3 246 525 (LICENTIA) * Abstract; figure 1; claim 1; page 6, lines lines 11-26 *	page 10,	1,2	
P,X	WO-A-8 809 591 (SINTEF) * Figure 2, abstract; Page 1, lines 22-34; page 4, line 4; page 5, lines 5-17; claims	line 26 -	1,2	
				TECHNICAL FIELDS SEARCHED (Int. Cl.5)
				H 04 L H 04 B H 03 M

The present search report has been drawn up for :

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